DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 47

VALUE OF THE HIGH-PRESSURE STEAM TEST OF PORTLAND CEMENTS

BY

R. J. WIG, Engineer Physicist

and

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(Continued on third page of cover.)

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By R. J. Wig and H. A. Davis

CONTENTS

I. INTRODUCTION

Unsoundness of a Portland cement, which is evidenced with age by a lack of cohesion and strength, may not be apparent for weeks or months after the cement is hydrated. This fact has created a demand for an accelerated test of soundness, in answer to which a large number of such tests have been proposed. All accelerated tests are designed to hasten the action of any expansive constituents of the cement, producing thereby evidence of unsoundness in a few hours or days.

High-pressure steam as a means of determining soundness apparently was first advocated in 1880 by Dr. Michaelas, who procured a German patent [1] on what he termed a boiling test

[1] Tonindustrie Zeitung, 1893, p. 8.

at higher temperatures in which the cement soundness test pieces were subjected in a steam-tight vessel to steam at 140° C to 180° C.

Dr. Erdmenger also advocated this test, and in 1881[2] published a description of his method of testing soundness of cement by means of high-pressure steam. He believed originally that it was the magnesia which caused unsoundness, and that this test detected the presence of magnesia in dangerous quantities. Later, however, he modified this opinion, as he found some cements which contained very little magnesia were unsound when exposed to high-pressure steam, while some cements containing a relatively large percentage of magnesia were found to be sound. For several years thereafter Dr. Erdmenger advocated the use of his high-pressure steam test in which he employed saturated steam at from 3 to 40 atmospheres pressure, and used pats, briquettes, and expansion bars for test pieces at various times.

It is the general opinion that the primary cause of unsoundness in Portland cement is attributable to the presence of free or loosely combined lime. Recent work by Phillips and Klein[3] in confirmation of this opinion reveals additional facts concerning the action of free lime in cement. Their conclusions may be summarized as follows:

> Free lime is generally noted in small amounts in well-burned, higher limed cements and in underburned, lower limed cements. On hydration, free lime, according to its fineness, hydrates as crystalline or amorphous calcium hydroxide. The disruption in cements in accelerated tests is due to the formation of the crystalline calcium hydroxide. Calcium hydroxide crystals are found in cement hydrated under normal conditions, but are not as large in size as those found in cement subjected to high-pressure steam.

Since there is no chemical means by which the percentage of free lime in cement can be determined and the identification of this constituent by optical means is difficult and limited, investigators have endeavored to find an economical physical test that would detect the presence of free lime in its dangerous form where it is liable to cause disintegration, cracking, and weakening of the cement.

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[2] Tonindustrie Zeitung, 1881, Nos. 24, 25, 26, and 27.
[3] Technologic Paper No. 42, Bureau of Standards.

To effect the quick expansion of the free lime or other expansive constituents, various experimenters have employed heat and water at various temperatures, steam at atmospheric pressure, and steam at pressures from 3 to 40 atmospheres. Accelerated tests may also be divided into qualitative and quantitative tests. In qualitative tests the unsoundness of the cement is exhibited by the development of cracks, the warping of test pieces, or their disintegration. In quantitative tests the amount of expansion of the cement or the effect on the strength of the cement is taken as the measure of the unsoundness.

In 1912 Force [4] recommended the use of a high-pressure steam test and in 1913 issued a specification which prescribed the following:

Soundness—Force Autoclave Test

Three neat briquettes to be made up in the usual manner and allowed to remain in the damp closet for 24 hours. At the expiration of that time the briquettes are to be removed from the molds and placed in the autoclave, sufficient water being added to partly or wholly cover the briquettes. The autoclave is then closed, the burners being of sufficient size to raise the pressure to 295 pounds in not more than one hour. The pressure of 295 pounds shall be maintained for one hour longer, or a total time of two hours. The pressure is then to be gradually released, the briquettes taken out and placed in the moist closet, where they shall be allowed to remain for one hour. At the end of that time they are to be broken in the standard cement testing machine in the usual manner. The average tensile strength of the three briquettes taken from the autoclave must show a tensile strength of not less than 500 pounds per square inch. They must also show an increase of not less than 25 per cent over the average tensile strength of three briquettes broken at the end of 24 hours. A bar of neat cement, 6 inches long by 1 inch square, shall be made up at the same time the briquettes are made. This expansion bar to remain in the moist closet for 24 hours and to be removed along with the briquettes and tested with the briquettes in the autoclave, as indicated above. After one hour in the moist closet, this expansion bar shall not show an expansion greater than one-half of 1 per cent.

Several railroads and other corporations adopted this test into their specifications, which brought about considerable controversy between its advocates and the cement manufacturers. Many of the cement manufacturers refused to furnish cement upon a specification which included this test, believing the test to be an abnormal one not in any way measuring the relative soundness or cementing value of Portland cement as used normally in concrete. It was also suggested that this test be in-

[4] Engineering News, Jan. 13, 1912.

June

cluded in the United States Government Specification for Portland Cement.

The work reported in this paper was limited to a physical investigation of the use of high-pressure steam as a means of determining the soundness of Portland cement both as a qualitative and quantitative test. In a number of instances the auxiliary tests are not as complete as might be desired, but they are of interest and therefore the results are included.

It is desired to thank the following cement companies for furnishing some of the cements used in these tests and also for their active interest in the work: Alpha Portland Cement Co., Alpha, N. J.; Atlas Portland Cement Co., Northampton, Pa.; Dexter Portland Cement Co., Nazareth, Pa.; Edison Portland Cement Co., New Village, N. J.; Lehigh Portland Cement Co., Ormrod, Pa.; and Universal Portland Cement Co., Universal, Pa.

Acknowledgment is also made to the Association of American Portland Cement Manufacturers for their cooperation in obtaining the samples, the chemical division of the Bureau of Standards for the chemical analyses of cements, and to G. M. Williams for his assistance in conducting the tests.

II. SCOPE OF INVESTIGATION

The investigation reported in this paper was made to establish, if possible, a relationship between the behavior of Portland cements in high-pressure steam and their physical properties under normal conditions of use and exposure, and to determine what value, if any, the high-pressure steam test has as a means of detecting unsoundness which might cause a weakening or disintegration of the cement or concrete.

III. PROPERTIES OF MATERIALS USED IN TESTS

1. CHEMICAL

The complete chemical analyses of the cements used in this investigation are given in Table 1.

2. PHYSICAL

The physical properties of the cements are given in Table 2, and the physical properties of the aggregates used in the concrete will be found in Table 3.

TABLE 1

Chemical analyses of cements

Brand of cement	Lab. No.	Silica (SiO_2)	Iron (Fe_2O_3)	Alumina (Al_2O_3)	Lime (CaO)	Magnesia (MgO)	Sulphuric anhydride (SO_3)	Loss on ignition	Insoluble residue
A1	345–13	20.94	1.95	7.01	63.12	3.52	1 50	2.15	0.13
A2	406–13	21.46	2.10	6.74	62.10	3.46	1.52	1.39	.12
B1	948–12	21.24	2.25	7.67	61.60	3.00	1.84	1.42	.73
B2	949–12	20.48	2.30	7.70	62.10	2.85	1.78	1.96	.68
B3	303–12	20.79	2.40	7.64	62.42	2.98	1.73	1.02	.32
C1	1171–13	20.52	2.30	7.00	63.00	3.04	1.66	2.01	.35
C2	243–13	21.12	2.10	7.36	62.20	3.22	1.61	1.33	.67
	243a–13	20.88	2.45	6.81	62.62	3.24	1.66	2.31	.41
C3	397–13	21.54	2.25	7.19	61.62	3.18	1.64	1.22	.73
	398–13	21.50	2.45	7.09	61.72	3.11	1.64	1.13	.73
C4	1209–12	20.96	2.30	7.20	61.90	3.13	1.68	2.50	.45
D1	378–13	21.66	2.60	5.84	63.32	2.63	1.38	1.40	.60
	379–13	20.20	2.80	7.12	63.80	2.70	1.51	1.78	.42
D2	441–13	19.86	2.55	7.39	63.08	2.83	1.44	1.84	.18
D3	863–12	20.12	2.40	7.46	62.70	3.34	1.33	2.85	.79
D4	875–12	20.24	2.55	6.95	62.56	3.26	1.48	2.81	.18
D5	882–12	20.04	2.75	6.81	62.54	3.25	1.30	2.77	.19
E1	312–13	23.76	2.40	5.36	62.86	3.11	1.33	.68	.35
	313–13	23.66	2.15	5.51	62.80	3.21	1.29	1.54	.58
E2	421–13	22.14	2.50	6.56	62.96	3.00	1.43	2.03	.19
F1	459–13	20.32	2.80	5.56	62.76	4.42	1.63	2.22	.43
F2	178–92–12	21.96	2.15	5.67	64.50	1.82	1.19	2.21	....
G1	1079–12	19.50	2.50	8.20	64.42	1.64	1.55	3.18	.22
G2	1080–12	19.56	2.50	8.10	63.72	1.70	1.45	2.95	.30
G3	1460–1–12	19.94	2.40	[a] 7.92	63.48	1.60	1.56	2.42	.87
G4	947–12	20.00	2.35	7.83	63.36	1.99	1.47	3.51	.73
G5	1081–12	21.64	2.50	6.42	63.94	1.80	1.63	1.72	.19
G6	175–6–13	19.54	3.50	[b] 7.92	62.94	1.54	1.55	2.02	.25
G7	442–13	19.64	3.07	[c] 8.31	62.90	1.35	1.55	2.48	.35
G8	435–12	20.04	2.85	[d] 8.49	63.06	1.91	1.56	1.67	.42
H1	532–12	19.42	7.35	5.71	63.36	1.06	1.25	1.18	.21
H2	901–12	19.80	7.73	5.35	63.22	1.11	1.29	1.46	.34
I1	1208–12	21.16	2.35	6.23	64.26	3.62	1.60	.94	.23
K	788–12	23.72	2.20	6.68	61.94	3.11	1.19	.62	.37
L	774–12	25.84	.30	6.46	61.76	1.34	1.75	1.74	.49
M	669–12	23.76	.30	7.42	62.76	1.13	1.38	3.04	.85

[a] Contains 0.47 per cent of Mn_3O_4.
[b] Contains 0.61 per cent of Mn_3O_4.
[c] Contains 0.64 per cent of Mn_3O_4.
[d] Contains 0.5 per cent of Mn_3O_4.

TABLE 2

Physical Properties and Tests of Cements

Brand of cement [a]	Lab. No.	Spec. grav.	Fineness, in per cent passing sieve—		Per cent water	Time of setting		Soundness [b] in standard steam 5 hours	Tensile strength [c] (lbs. per sq. in.)				Behavior in steam tests				Tensile strength (lbs. per sq. inch) Age 48 hours	
									7 days		28 days		Standard specifications		High-pressure steam			
			No. 100	No. 200		Initial	Final		Neat	Sand	Neat	Sand	Failed	Passed	Failed	Passed	After steam treatment at high pressure	Untreated
						h. m.	h. m.											
A^1	345–13	3.17	94.2	76.2	21.5	3 15	7 25	O. K.	695	243	789	350	....	3–18–13	3–22–13 5–13–13	5–30–13	(d)	....
A^2	406–13	3.15	94.8	75.6	21.0	2 55	6 45	O. K.	747	278	715	404	....	4– 3–13	....	3–31–13	483	258
B^1	948–12	3.15	94.2	75.0	21.5	2 15	6 45	O. K.	538	189	638	306	....	7–24–12	7–17–12 7–31–12	8– 2–13	(d)	....
B^2	949–12	[e] 3.04 [f] 3.14	94.0	75.6	21.5	2 10	6 40	O. K.	614	212	736	337	....	7–24–12	....	6–10–12	452	282
B^3	303–12	3.15	96.4	79.0	22.5	3 30	6 45	O. K.	647	320	713	364	....	4– 8–12	4–30–12	8– 5–12	(g)	(g)
C^1	1171–13	3.10	98.6	87.2	22.4	4 25	6 25	O. K.	812	296	773	376	....	6–28–13	6–28–13	....	....	....
C^2	243–13	3.15	97.0	82.6	22.4	3 35	8 20	O. K.	731	356	724	414	....	3–11–12	3–10–12	4– 5–12	(d)	....
	243–13	3.18	95.6	77.6	22.4	3 30	7 35	O. K.	673	327	793	404	....	3–21–12	3–22–12	4– 5–12	(d)	....
C^3	397–13	3.16	98.2	87.4	23.4	3 05	6 45	O. K.	846	349	631	429	....	3–31–13	....	3–31–13	530	316
	398–13	3.15	98.6	85.3	23.4	3 20	7 50	O. K.	778	386	677	455	....	3–31–13	....	3–31–13	588	253
C^4	1209–12	3.10	97.2	82.4	22.0	3 20	5 50	O. K.	668	293	765	341	....	9–12–12	....	9–10–12	(g)	(g)
D^1	379–13	3.15	96.6	77.6	25.5	3 20	7 40	(h)	435	200	509	264	3–25–12	3–27–13	3–25–13	5–23–13	(d)	....
	379–13	3.14	96.4	78.8	25.5	3 25	7 55	(h)	553	230	554	307	3–25–12	3–27–13	5–12–13	5–23–13	(d)	....
D^2	441–13	3.13	97.2	82.2	27.0	4 30	8 40	O. K.	535	278	562	343	....	4–15–13	....	4–17–13	424	222
D^3	863–12	3.12	94.4	76.6	24.0	3 05	8 05	O. K.	538	225	617	311	....	7–24–12	7–26–12	....	(g)	(g)
D^4	875–12	3.11	93.6	76.0	24.0	2 25	6 40	O. K.	534	365	577	413	....	7–24–12	7–26–12	....	(g)	(g)
D^5	882–12	3.09	94.4	77.6	24.0	2 20	6 35	O. K.	650	195	610	256	....	7–24–12	7–25–12	....	(g)	(g)

E^1	312–13	3. 22	92. 4	72. 5	20. 0	3 40	7 55	([i])	684	210	851	293	3–16–13	4– 7–13	4– 7–13	12– 1–13	([d])	...
		3. 21	93. 0	72. 9	20. 0	3 40	7 45	([i])	701	204	830	301	3–16–13	4– 7–13	7–12–13	12– 1–13	([d])	...
E^2	421–13	3. 21	94. 6	80. 6	21. 5	4 25	8 30	O. K.	557	287	690	380	...	4– 8–13	...	4–12–13	454	289
F^1	459–13	3. 17	94. 4	83. 3	20. 8	5 15	9 00	([j])	811	217	827	304	4–25–13	5–12–13	5–12–13	5–23–13	([d])	...
													4–29–13					
F^2	178	...	...	...	...	...	...	...	...	...	...	...	2– 8–12	...	...	4–23–12	([g])	([g])
	192–12																	
G^1	1079–13	3. 11	97. 6	86. 0	22. 0	2 15	5 15	O. K.	615	282	780	320	...	7–29–13	7–30–12	9– 5–12	([d])	...
															8–20–12			
G^2	1080–12	3. 08	97. 2	79. 2	22. 0	2 15	5 10	O. K.	630	273	693	337	...	8–10–12	[k] 7–24–12	...	...	...
															8–20–12			
G^3	1460–12	3. 12	96. 0	75. 0	22. 2	2 40	6 55	O. K.	532	235	701	321	...	11– 4–12	[k] 11– 4–12	...	...	...
	1461–12	3. 10	95. 0	75. 0	22. 2	2 35	6 50	O. K.	603	224	682	344	...	11– 4–12	[k] 11– 4–12	...	...	...
G^4	947–12	[e] 3. 05	96. 2	76. 2	22. 0	1 50	6 35	O. K.	655	213	737	313	...	7–13–12	...	7–16–12	457	421
		[f] 3. 12																
G^5	1081–12	3. 10	97. 2	85. 6	22. 0	2 10	5 25	O. K.	682	264	834	382	...	7–25–12	...	7–26–12	513	389
G^6	175–13	3. 14	97. 6	75. 2	22. 0	3 00	5 40	([d])	539	215	726	314	[k] 2–19–13	...	...	...	...	...
G^7	442–13	3. 12	95. 6	78. 4	21. 5	3 05	6 50	O. K.	669	265	708	335	...	4–16–13	4–23–13	...	([g])	([g])
G^8	435–12	3. 12	96. 6	80. 6	21. 8	2 45	6 05	O. K.	([g])	([g])	([g])	([g])	...	4–11–12	...	4–27–12	([g])	([g])
H^1	532–12	3. 24	98. 2	87. 6	22. 0	4 00	7 45	O. K.	836	332	793	337	...	4–30–12	...	5– 2–12	([g])	([g])
H^2	901–12	3. 22	98. 4	85. 6	22. 0	3 30	8 15	O. K.	723	259	885	342	...	7–24–12	...	7–26–12	([g])	([g])
I	1208–12	3. 14	98. 2	85. 2	22. 0	3 10	5 55	O. K.	703	316	721	359	...	9–12–12	...	9–10–12	([g])	([g])
K	788–12	3. 21	94. 0	75. 0	22. 0	3 10	7 10	O. K.	595	216	683	307	...	7–16–12	7–19–12	8– 5–12	([g])	([g])
L	774–12	3. 15	98. 6	86. 4	22. 0	0 35	2 00	O. K.	([g])	([g])	([g])	([g])	...	7–12–12	...	7–16–12	([g])	([g])
M	669–12	3. 10	98. 8	83. 6	25. 0	4 05	7 25	O. K.	([g])	([g])	([g])	([g])	...	6– 7–12	...	6–12–12	([g])	([g])

[a] All Portland cement except L, which is a white Portland, and M, which is sold as a nonstaining cement. Different brands are indicated by separate letters, while different samples are indicated by numeral subscripts.
[b] All cement sound in air and water when examined at end of 28 days.
[c] All tensile strength values are the average of 3 test pieces.
[d] Disintegrated.
[e] As received.
[f] After ignition.
[g] No briquettes made.
[h] Cracked and disintegrated.
[i] Warped and soft; warped and disintegrated.
[j] Complete disintegration.
[k] No further tests made.

TABLE 3

Physical Properties of Aggregates

Aggregate [a]	Weight per cubic foot (pounds)	Specific gravity	Per cent of voids computed	Mechanical analyses		
				Number of mesh	Opening in inches	Per cent passing
Potomac River sand	104	2.66	37.2	3	0.263	100.0
				4	.185	99.4
				6	.131	96.6
				8	.093	91.7
				10	.065	85.6
				14	.046	80.0
				20	.0328	71.0
				28	.0232	54.8
				35	.0164	37.9
				48	.0116	18.9
				65	.0082	9.3
				100	.0058	3.7
				150	.0041	1.9
				Screen (inches)		
Potomac River washed gravel	104	2.60	35.8	2.0	2.0	100.0
				1.5	1.5	96.5
				1.0	1.0	74.9
				.75	.75	59.8
				.50	.50	39.4
				.25	.25	13.4

[a] Both aggregates were composed chiefly of silicious material, were clean, and practically free from clay or loam.

IV. DESCRIPTION OF TESTS

The qualitative high-pressure steam test used throughout this paper consists of subjecting an ordinary soundness pat, which has been stored for 24 hours in a damp closet, to a steam pressure of 300 pounds per square inch for at least one hour, the total time in the high-pressure boiler being three hours. A cement was said to pass this test when it exhibited no cracking, warping, or disintegration on examination after the treatment. The quantitative high-pressure steam test consists of molding six briquettes of neat cement at normal consistency, storing these test pieces 24 hours in a damp closet, then subjecting three of them to an atmosphere of steam at 300 pounds pressure for at least one hour; total time in the high-pressure boiler being three hours. The briquettes (both treated and untreated) are then broken in

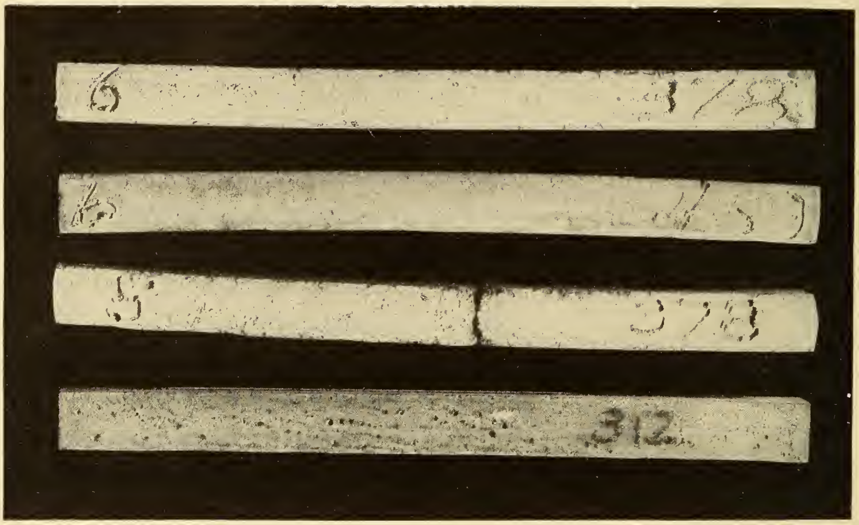

FIG. 1*a*.—*Neat cement prisms after storing for two years in air under cover*

All of the above prisms contained cement that passed the standard atmospheric steam test but failed in high-pressure steam at the time the prisms were molded. These prisms were merely stored in air and never treated in steam. Note the warping of all prisms and the partial disintegration of one prism marked 5–378, which broke in handling

FIG. 1*b*.—*Effect of high-pressure steam on neat cement and mortar briquets*

All of the above half briquets contained cement that failed in the high-pressure steam test. Half briquets on the left are composed of 1:3 standard sand mortar. The one on the extreme left has been treated in steam at 180 pounds pressure for five hours, while the other half has not been treated. Half briquets on the right are composed of neat cement. The left one has been treated in steam at 180 pounds pressure for five hours, while the extreme right one has not been treated in steam

a shot-testing machine. A cement was said to pass this test when the treated briquettes exhibited greater strength than the untreated ones. Throughout this paper cements are classified into three types, respectively:

(1) A cement which fails to pass the standard atmospheric steam test.

(2) A cement which passes the atmospheric steam test but fails when treated in high-pressure steam.

(3) A cement which passes both atmospheric and high-pressure steam tests.

1. SOUNDNESS TESTS

Of a number of the routine samples of cement of various brands received in the Bureau laboratory, four soundness pats were made; one was stored in air at approximately 20° C (68° F), another placed in water at 20° C (68° F), the third treated in steam over boiling water at atmospheric pressure for five hours, while the fourth was subjected to 300 pounds steam pressure for at least one hour, total time in the high-pressure boiler being three hours. The results to date show, first, that all the type 1 cement that failed in the atmospheric steam test also finally failed as a neat cement pat stored in air, although they were sound at the 28-day period; and, second, that some of the cement classified as type 2 failed in air, while no cement of type 3, which passed the high-pressure steam test, failed in air. With one exception, all pats stored in water when last examined were sound. The cement which failed within two years showed some warping and was a type 2 cement. (See Fig. 1*a*.)

In Table 2 the results of the routine tests, including high-pressure steam tests of the cements used in the strength and linear change tests, are given.

In order to ascertain what proportion of the cements as at present manufactured were sound after exposure in high-pressure steam, all routine samples received for a period of about nine months were subjected to the qualitative high-pressure steam test, and the results are shown in Table 4 below. The qualitative high-pressure steam test was employed because the amount of cement which could be spared for these experiments was necessarily

small. The effect of high-pressure steam on neat cement which was unsound in high-pressure steam and one to three mortar of this cement is shown in Fig. 1*b*.

TABLE 4

Results of Tests of Portland Cement in High-Pressure Steam

Samples tested	Samples sound	Samples unsound	Brands sound	Brands unsound	Brands sound at one time, unsound at others
564	438	126	35	16	[a] 6
61 [b]	51	10	5	1	[a] 1

[a] These brands are included in other two columns.
[b] White Portland and natural so-called nonstaining cements.

In order to determine the effect of a small amount of free lime on the soundness of a cement, the following tests were made: Samples of chemically pure calcium carbonate, calcium sulphate, calcium nitrate, and limestone from the raw material taken at a cement mill were ignited in a vacuum furnace for a total time of from two to two and one-half hours, the maximum temperatures of 1400° C and 1700° C were maintained for at least one hour, and this calcined material added to a sound cement in two proportions, 0.5 and 4 per cent, respectively. The results are given below in Table 5. None of the compounds burned at either 1400° C (2552° F) or 1700° C (3092° F) when added to the cement to the amount of 0.5 per cent caused unsoundness even in high-pressure steam. It is observed that the limestone ignited at 1400° C and added to the amount of 4 per cent to a sound cement caused it to disintegrate, while the same cement, to which 4 per cent of the other calcium compounds ignited at the same temperature was added, was sound after exposure in both the atmospheric and high-pressure steam test.

TABLE 5

Results of Soundness Tests of Portland Cement to which Calcined Limestone, Calcium Carbonate, Sulphate, and Nitrate were added

Compound [a]	Temperature to which compound was heated	Per cent of ignited compound added to cement	Treatment of pat	Result of treatment
	°C [b]			
1	1400	0.5	In steam at atmospheric pressure, 5 hours.	All sound.
2	1400	0.5		
3	1400	0.5		
4	1400	0.5		
1	1400	0.5	In steam at 300 pounds, 1 hour; total time, 3 hours.	All sound.
2	1400	0.5		
3	1400	0.5		
4	1400	0.5		
1	1700	0.5	In steam at atmospheric pressure, 5 hours.	All sound.
2	1700	0.5		
3	1700	0.5		
4	1700	0.5		
1	1700	0.5	In steam at 300 pounds, 1 hour; total time, 3 hours.	All sound.
2	1700	0.5		
3	1700	0.5		
4	1700	0.5		
1	1400	4	In steam at atmospheric pressure, 5 hours.	Sound.
2	1400	4		Sound.
3	1400	4		Sound.
4	1400	4		(c)
1	1400	4	In steam at 300 pounds, 1 hour; total time, 3 hours.	Sound.
2	1400	4		Sound.
3	1400	4		Sound.
4	1400	4		(c)
1	1700	4	In steam at atmospheric pressure, 5 hours.	(c)
2	1700	2		Sound.
3	1700	4		(c)
4	1700	4		(c)
1	1700	4	In steam at 300 pounds, 1 hour; total time, 3 hours.	(c)
2	1700	2		Sound.
3	1700	4		(c)
4	1700	4		(c)

[a] Compound 1, calcium carbonate; compound 2, calcium sulphate; compound 3, calcium nitrate; compound 4, limestone from raw material taken at cement mill.

[b] This temperature was maintained in vacuum furnace for at least 1 hour; total time in furnace from 2 to 2½ hours.

[c] Completely disintegrated before treating in steam.

2. STRENGTH TESTS

A series of mortar strength tests were made, employing nine different samples of cement, comprising five different brands, three of these being of cements of type 1, failing to pass standard atmospheric steam test and the high-pressure steam test two of type 2, which passed in the atmospheric steam test and failed in the high-pressure steam test, and four of type 3, passing the high-pressure steam test and the atmospheric steam test. The mortar was composed of one part cement to three parts standard Ottawa sand, by weight, mixed at a consistency corresponding to the normal consistency of the cement used and molded by hand in brass molds. Both briquettes and 2-inch cubes were molded, and the test pieces were tested, or are to be tested, at various intervals up to 10 years. The results of these tests up to the present time are shown in Table 6 and diagrammatically in Figs. 2 and 3. All test pieces were stored in air except where noted.

A series of concrete strength tests were made to determine the cementing value of the three types of cements as normally used in concrete mixtures without exposure to steam. Eighteen samples of cement were employed, comprising seven different brands, four of these samples being of type 1, seven of type 2, and seven of type 3. The test pieces were concrete cylinders 8 inches in diameter by 16 inches high. The concrete was composed of one part cement, two parts Potomac River sand, and four parts washed Potomac River gravel, by volume. A medium consistency was employed containing about 9 per cent of water and the concrete was mixed in a one-half-yard cube mixer and molded by hand in steel molds. These cylinders, of which 45 were molded for each sample of cement, were tested, or are to be tested, at various intervals up to 10 years. All test pieces were kept in a damp place for 30 days, and then stored in air outdoors for the remaining time prior to testing. Three test pieces were tested at each test period, and the modulus of elasticity, together with the yield point, was determined on at least two of the cylinders of each set.

The results of the concrete strength tests to date are shown in Table 7 and diagrammatically in Fig. 4.

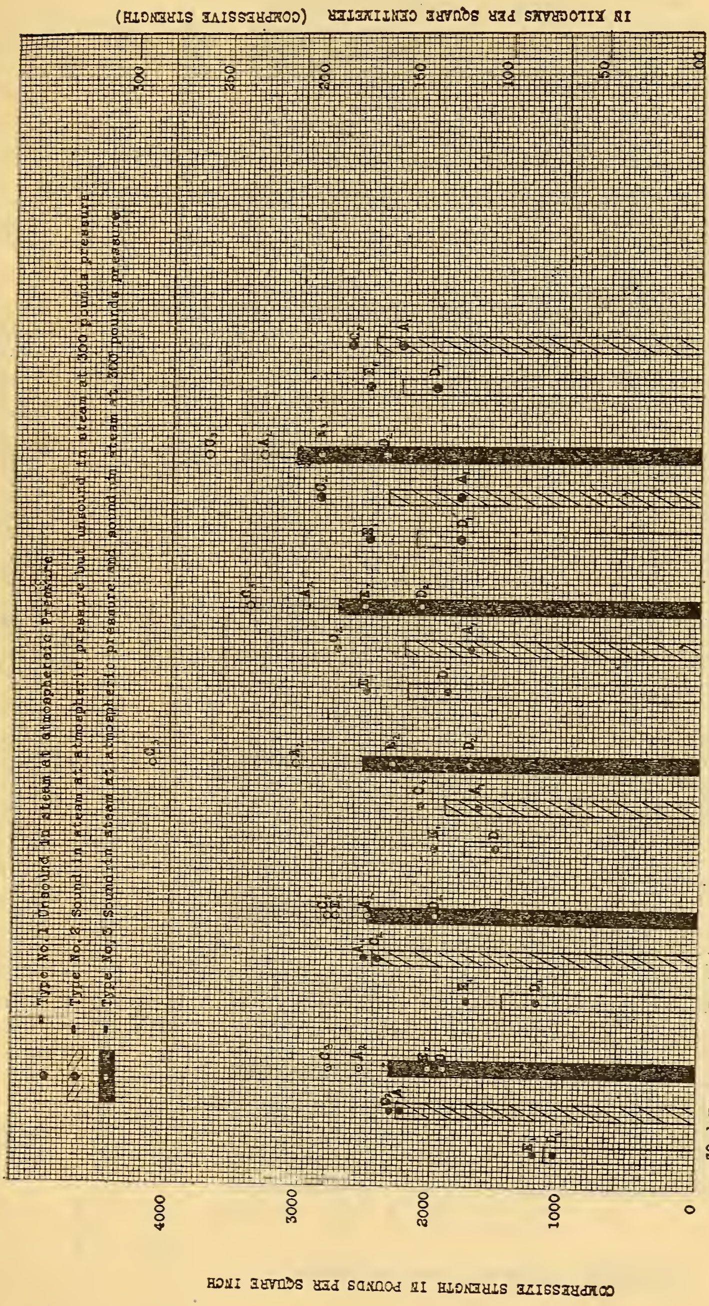

FIG. 2.—*Compressive strength of cement mortar made in connection with the investigation of the high-pressure steam test for Portland cement*

One part Portland cement to three parts standard Ottawa sand. Stored in air under cover at about 20° C. Each result is the average of tests of three 2-inch cubes.

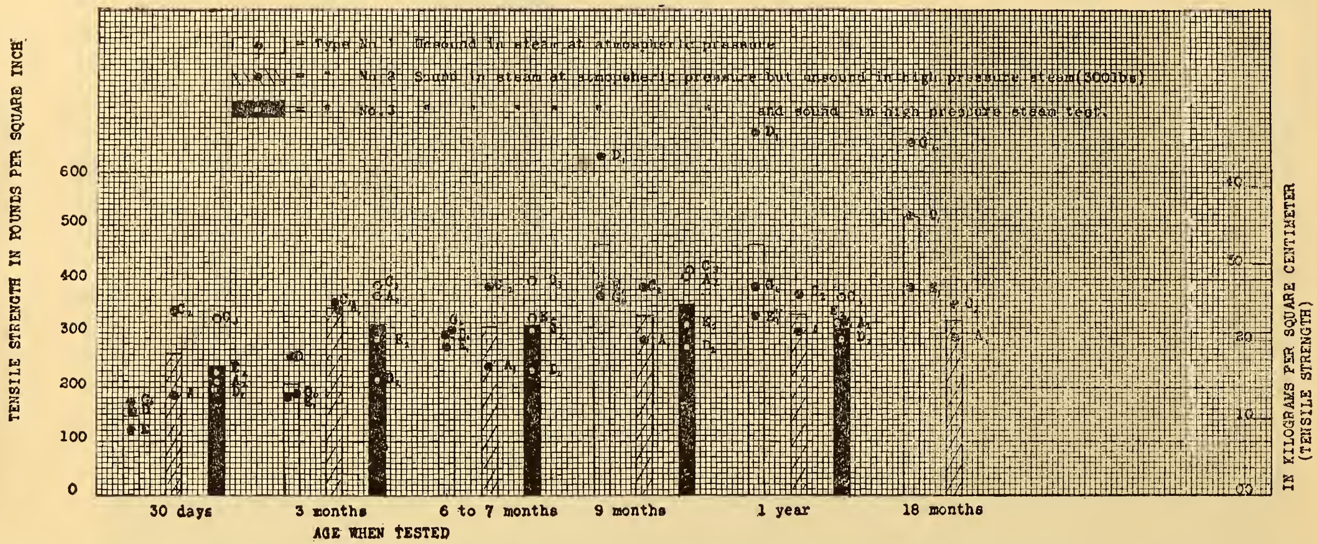

FIG. 3.—*Tensile strength of cement mortar made in connection with the investigation of the value of the high-pressure steam test for Portland cement.*

One part Portland cement to 3 parts standard Ottawa sand. Stored in air under cover at about 20° C. Each result is the average of tests of five standard briquettes.

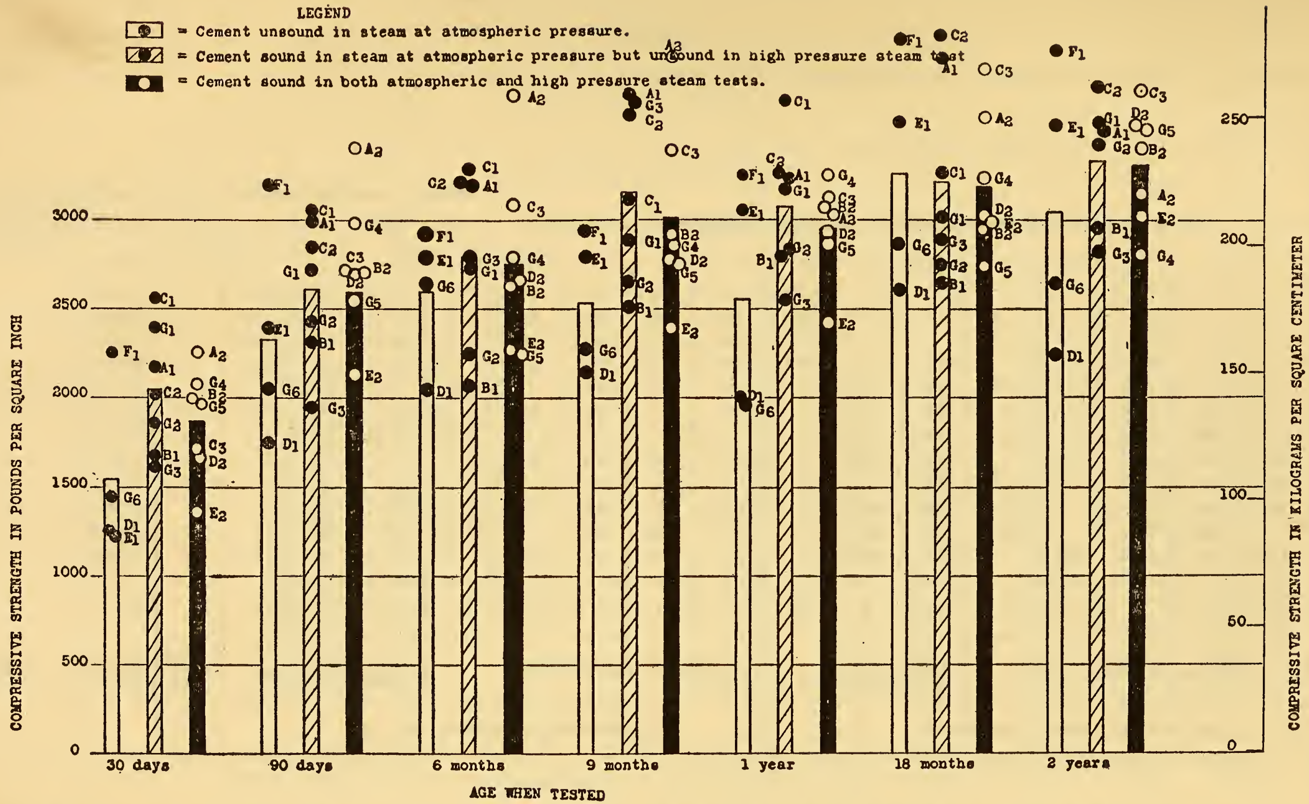

FIG. 4.—*Compressive strength of concrete cylinders made in connection with the investigation of the value of the high-pressure steam test for Portland cement*

Proportions: 1:2:4 by volume; 9 per cent water used; aggregates are Potomac River sand and washed gravel; stored in air outdoors. Each dot represents the average result of three tests of 8 by 16 inch cylinders. Different brands are designated by letter and separate shipments by subnumbers.

TABLE 6

Mortar Strength Tests Made in Connection with the Investigation of the Value of the High-Pressure Steam Test

[One part Portland cement, 3 parts standard Ottawa sand; stored in air except where noted]

Brand of cement	Lab. No.	Type of cement[a]	Tensile strength[b] (lbs. per sq. in.)									Compressive strength (lbs. per sq. in.)						
			Age in weeks when tested			Age in months when tested						Age in weeks when tested		Age in months when tested				
			1	4	13	6	7	9	12	18	24	4	13	6	7	9	12	18
A^1	345-13	2	....	186	341	....	238	290	302	293	....	2220	2508	....	1655	1720	1805	2268
A^2	406-13	3	....	209	368	305	....	406	317	....	....	2540	2481	3040	....	2960	3300	....
C^2	243-13	2	....	340	355	....	386	383	371	354	....	2290	2405	2102	....	2735	2870	2640
C^3	397-13	3	....	325	387	398	....	416	367	....	....	2775	2790	4140	....	3400	3715	3440
D^1	378-13	1	....	156	256	....	299	627	671	519	....	1072	1210	....	1532	1890	1800	2000
D^2	441-13	3	....	199	212	231	....	274	290	....	....	1915	1970	1730	....	2090	2380	....
E^1	312-13	1	....	120	182	....	276	386	333	381	....	1220	1735	....	1990	2510	2500	2490
E^2	421-13	3	....	227	289	329	....	316	320	....	....	2020	2730	2320	....	2530	2875	....
G^6	176-13	1	179	171	186	....	305	369	387	655	817	....	....	....	....	....	....	....
G^6	176-13	1	[c] 216	[c] 294	[c] 308	....	[c] 281	[c] 298	[c] 308	[c] 303	[c] 281	....	....	....	....	....	....	....
G^{6d}	176-13	1	469	401	576	....	543	607	548	665	670	....	....	....	....	....	....	....
G^{6d}	176-13	1	[c] 648	[c] 658	[c] 726	....	[c] 777	[c] 660	[c] 709	[c] 750	[c] 708	....	....	....	....	....	....	....

[a] See p. 11.
[b] In the tensile-strength tests, each value is the average of tests of 5 briquettes; compressive-strength tests, each value is the average of three 2-inch cubes.
[c] Stored in water.
[d] In the tensile-strength tests neat-cement briquettes were used.

TABLE 7

Compressive Strength, in Pounds per Square Inch, of Concrete Cylinders Made in Connection with the Investigation of the Value of the High-Pressure Steam Test

[Concrete composed of 1 part Portland cement, 2 parts Potomac River sand, and 4 parts washed Potomac River gravel; percentage of water 9; stored in air outdoors; each result is the average of 3 test pieces.]

Brand of cement, etc.	Lab. No.	Type of cement [a]	Property determined	Age, in weeks, when tested (lbs. per sq. in.)		Age, in months, when tested (lbs. per sq. in.)				
				4	13	6	9	12	18	24
A[1]	345–13	2	Compressive strength	2178	2994	3197	3700	3237	3903	3512
			Modulus of elasticity	3 130 300	3 970 000	3 713 000	3 175 000	3 775 000	3 590 000	3 708 000
			Yield point	1275	1755	1680	2070	1920	2200	1930
A[2]	406–13	3	Compressive strength	2257	3400	3697	3910	3033	3573	3154
			Modulus of elasticity	3 150 000	3 862 000	3 903 000	3 960 000	3 333 000	4 150 000	3 810 000
			Yield point	1085	1750	2230	2035	1960	2070	1700
B[1]	948–12	2	Compressive strength	1680	2310	2875	2501	2790	2650	2960
			Modulus of elasticity	2 046 000	2 740 000	3 196 000	2 840 000	3 361 000	3 103 000	2 980 000
			Yield point	763	1287	900	1380	1325	1260	1450
B[2]	949–12	3	Compressive strength	1988	2690	2630	2909	3062	2953	3408
			Modulus of elasticity	2 459 000	3 350 000	3 220 000	3 265 000	3 030 000	3 397 000	3 260 000
			Yield point	697	1433	1350	1630	1615	1410	1760
C[1]	1171–13	2	Compressive strength	2560	3050	3205	3117	3663	3277	....
			Modulus of elasticity	3 025 000	3 070 000	2 540 000	3 170 000	3 060 000	3 325 000	....
			Yield point	1570	1650	1860	1660	2025	1750	....
C[2]	243–13	2	Compressive strength	2017	2841	3283	3577	3258	4045	3749
			Modulus of elasticity	2 825 000	3 611 000	3 745 000	3 485 000	3 835 000	3 958 000	3 983 000
			Yield point	1110	1787	1675	2130	1800	1950	1640

[a] See p. 11.

TABLE 7—Continued

Brand of cement, etc.	Lab. No.	Type of cement	Property determined	Age, in weeks, when tested (lbs. per sq. in.)		Age, in months, when tested (lbs. per sq. in.)				
				4	13	6	9	12	18	24
C^3	397–13	3	Compressive strength	1717	2713	3080	3383	3123	3853	3729
			Modulus of elasticity	3 015 000	3 091 000	3 450 000	2 910 000	3 091 000	3 517 000	3 688 000
			Yield point	790	1500	1825	2040	1750	2100	1800
D^1	378–13	1	Compressive strength	1257	1753	2047	2145	2005	2610	2243
			Modulus of elasticity	2 380 000	3 053 000	3 660 000	3 020 000	3 280 000	3 275 000	4 245 000
			Yield point	490	1000	1030	1040	935	1225	983
D^2	441–13	3	Compressive strength	1675	2700	2658	2778	2937	3027	3531
			Modulus of elasticity	2 930 000	4 120 000	4 185 000	3 691 000	3 510 000	4 165 000	4 080 000
			Yield point	855	1625	1490	1370	1840	1875	2090
E^1	312–13	1	Compressive strength	1222	2309	2788	2793	3058	3547	3535
			Modulus of elasticity	3 100 000	3 170 000	3 110 000	2 842 500	3 750 000	3 888 000	4 037 000
			Yield point	580	1300	1445	1690	1750	1650	1727
E^2	421–13	3	Compressive strength	1360	2135	2270	2395	2422	2983	3032
			Modulus of elasticity	2 390 000	3 285 000	3 745 000	3 050 000	3 306 000	4 140 000	3 940 000
			Yield point	660	1240	1240	1330	1250	1860	1510
F^1	459–13	1	Compressive strength	2256	3197	2923	2940	3252	4017	3953
			Modulus of elasticity	2 960 000	2 935 000	3 105 000	2 940 000	3 175 000	4 040 000	4 215 000
			Yield point	845	1850	1410	1870	1865	3100	1695
G^1	1079–12	2	Compressive strength	2390	2720	2735	2883	3167	3017	3541
			Modulus of elasticity	2 541 000	3 157 000	3 453 000	3 627 000	2 970 000	3 030 000	3 115 000
			Yield point	963	1390	1293	1490	1730	1675	1900
G^2	1080–12	2	Compressive strength	1860	2430	2250	2656	2803	2757	3432
			Modulus of elasticity	2 603 000	2 696 000	3 450 000	3 250 000	3. 415 000	2 925 000	3 485 000
			Yield point	597	1183	860	1375	1450	1470	1780

G^3	1460–12	2	Compressive strength	1615	1950	2792	3657	2555	2888	2827
			Modulus of elasticity	2 500 000	2 920 000	4 020 000	3 875 000	3 136 000	3 340 000	3 140 000
			Yield point	783	1150	1470	1800	1520	1505	1900
G^4	947–12	3	Compressive strength	2074	2980	2690	2865	3250	3237	2807
			Modulus of elasticity	2 980 000	3 123 000	3 050 000	3 240 000	3 145 000	3 050 000	2 465 000
			Yield point	577	1450	1385	1500	1670	1890	1500
G^5	1081–12	3	Compressive strength	1972	2550	2250	2766	2870	2746	3517
			Modulus of elasticity	2 131 000	3 006 000	3 510 000	2 855 000	2 665 000	2 755 000	3 725 000
			Yield point	713	1240	1097	1245	1450	1500	1850
G^6	175–13	1	Compressive strength	1442	2050	2640	2277	1965	2865	2447
			Modulus of elasticity	1 962 000	3 315 000	2 810 000	3 070 000	2 910 000	3 077 000	3 257 000
			Yield point	650	1025	1215	1440	910	1630	970
Summary with reference to type of cement										
Type		1	Compressive strength	1544	2327	2599	2531	2556	3260	3045
			Modulus of elasticity	2 580 000	3 143 000	3 171 000	2 968 000	3 279 000	3 570 000	3 939 000
			Yield point	641	1294	1275	1510	1365	1901	1344
Type		2	Compressive strength	2043	2614	2791	3156	3067	3220	3337
			Modulus of elasticity	2 667 000	3 166 000	3 445 000	3 346 000	3 364 000	3 324 000	3 420 000
			Yield point	1009	1457	1391	1701	1681	1687	1767
Type		3	Compressive strength	1867	2596	2754	3001	2957	3196	3311
			Modulus of elasticity	2 722 000	3 405 000	3 580 000	3 281 000	3 154 000	3 596 000	3 567 000
			Yield point	768	1463	1517	1593	1648	1815	1744

A study of the effect of various steam pressures on cement passing the standard steam test is shown in Table 8. This table includes the results of tests of steam-treated mortar specimens two days old (just after removal from steam boiler), and similar results of tests when the steam-treated specimens are 28 days old. The results show that after the steam pressure has been raised to 100 pounds there is practically no increase in strength due to storing the treated test specimens for an additional 26 days in water before testing. The maximum tensile strength for this cement appears to have been attained with 140 pounds steam pressure.

An investigation reported in Technologic Paper No. 5,[5] which contains the results of tests of 8 by 16 inch mortar and concrete cylinders exposed to steam at pressures up to 80 pounds per square inch for various durations, showed that this treatment increases the compressive strength several hundred per cent, the maximum strength being obtained at the maximum steam pressure and duration.

[5] The Effect of High-Pressure Steam on the Crushing Strength of Portland Cement Mortar and Concrete; Technologic Paper No. 5, Bureau of Standards.

TABLE 8

Effect of Various Steam Pressures on Tensile and Compressive Strength of 1:3 Portland Cement Standard Ottawa Sand Mortar

Cement[a]	Steam pressure (lbs. per sq. in.)	Tensile strength (lbs. per sq. in.)		Compressive strength (lbs. per sq. in.)	
		48 hours	28 days	48 hours	28 days
A	10	118	261	....	....
A	20	117	218	1,915	2,591
A	40	115	190	1,176	2,262
A	60	151	215	1,750	2,385
A	80	195	260	1,890	2,178
A	100	294	315	3,397	2,867
A	100	381	366	....	....
A	100	[b] 514	425	....	....
A	120	385	358	2,485	2,353
A	140	410	411	2,965	2,537
A	160	363	355	2,912	2,327
A	180	362	286	3,198	3,050
A	180	[c] 369	[c] 256	3,416	3,079
A	180	[d] 398	[d] 272	....	....
B	200	245	288	....	....
B	275	[e] 218	193	....	....
B	225	[f] 211	219	....	....

[a] All subjected to steam at stated pressures for 5 hours unless otherwise noted. Both cements A and B passed the standard soundness test. All test pieces placed in boiler after 24 hours in damp room. Al values are the average of 3 test pieces.

[b] Age, 7 days. Under pressure at 100 pounds for 15 hours.

[c] Two periods of 5 hours each.

[d] Three periods of 5 hours each.

[e] Exposed to one period of 5 hours at 200 pounds pressure then one period of 5 hours at 275 pounds.

[f] Exposed to 5-hour periods each at 200 pounds, 275 pounds, and 225 pounds pressure.

3. LINEAR CHANGE TESTS

Tests were made on a large number of cement samples of various brands and comprising the different types of cement to determine the linear change occurring in these cements when stored in air, water, or treated in high-pressure steam. The test pieces employed were 1 by 1 by 13 inch prisms, and in most of the tests they were composed of neat cement gaged at normal consistency. For the first 24 hours after molding all test pieces were stored in a damp closet. They were then removed, and

by means of a mounted micrometer reading to thousandths of an inch the original reading was made. All the molds in which the test pieces were made were approximately 13 inches in length, and this was considered the original length by which all changes in length were divided to determine the per cent of linear change.

The results of the tests made on prisms stored in air and water are given in Table 9.

The effect on the length of the prisms of treating them in high-pressure steam is shown in Table 10. Fig. 5 shows one of these prisms of cement unsound in high-pressure steam before and after exposure to steam.

The effect on the length of these cement prisms of storing them in air and water is also shown in Fig. 6. While the results obtained with different cements overlap a good deal, it is evident that there is a tendency for the type 3 cement to show more contraction in air and less expansion in water than the type 2 cement. This would indicate that the type 2 cement contained a certain amount of expansive material, which in time tended to counteract the effect of contraction due to drying in air and added to the expansion caused by immersion in water. If this be definitely established, a type 3 cement would be less desirable than a type 2 cement in ordinary construction work exposed in the air.

Several tests were made to determine the linear change which occurred with cements to which sand or waterproofing compound are added. To one cement failing in the high-pressure steam test an equal part of standard Ottawa sand was added and a prism molded. This prism was then subjected to 180 pounds steam pressure for five hours and the linear expansion determined. A similar test prism containing one part cement to two parts standard sand was molded and treated in high-pressure steam. It was found that the linear expansion of the 1 : 1 mortar was 96 per cent of that of the neat cement, and the 1 : 2 was 69 per cent of that of the neat. All test specimens received the same steam treatment. To one cement 2 per cent of an integral antipathetic waterproofing compound, composed of stearic acid and lime, was added, and its effect on the linear change of test prisms stored in air and water was studied. The results show that the presence of the waterproofing compound had no effect on the linear change.

FIG. 5.—*Neat cement prisms before and after treating in high-pressure steam*

Both prisms contained cement that failed when exposed to high-pressure steam test. Prism No. 15 after treating in steam at 180 pounds pressure for five hours increased 4.7 per cent of original length. Prism No. 16 before treating in high-pressure steam

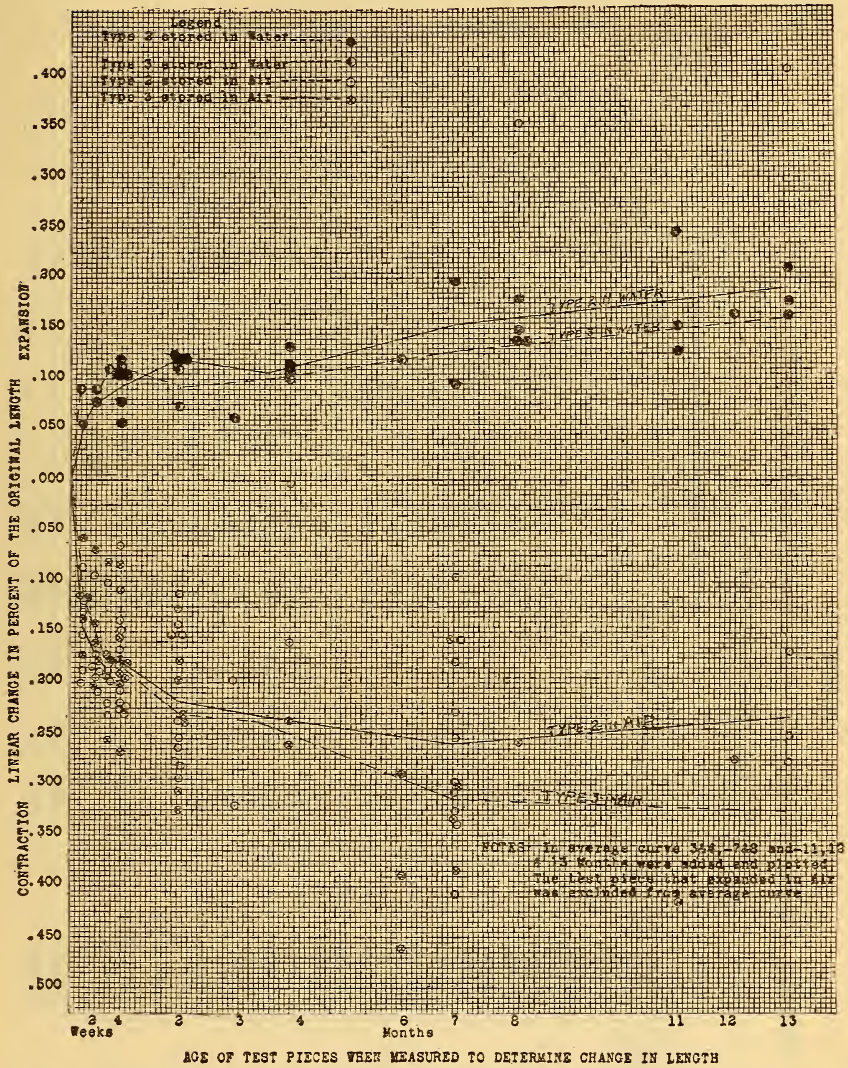

FIG. 6.—*Linear change of neat cement prisms stored in air and water made in connection with the investigation of the value of the high-pressure steam test for Portland cement*

Each dot represents the average results given in Table 9. Test pieces 1 by 1 by 13 inches neat cement prisms. Linear change in per cent of original length.

TABLE 9

Summary of Linear-Change Tests of Neat Cement Stored in Air and Water

[Test pieces 1 by 1 by 13 inch prisms]

Brand of cement [a]	Lab. No.	Type of cement [b]	Manner of storing	Test pieces, with average and range	Linear change in per cent of original length [c]												
					Age, in weeks, of test pieces				Age, in months, of test pieces								
					1	2	3	4	2	3	4	6	7	8	11	12	13
A[1]	345-13	2	Air	2 Average				0.182	0.237				0.254				d 0.277
				Range				.025	.009				.002				
B[1]	948-12	2	Air	6 Average	0.132	0.195	0.232	.228	.282	e 0.321			.408				
				Range	.019	.036	.035	.020	.025	.007			.010				
B[1]	948-12	3	Air	4 Average	.173	.204	.257	.269	e .306			e 0.461	e .385				
				Range	.062	.075	.041	.080	.007			.039	.022				
C[2]	243-13	3	Air	2 Average				.192	.177		0.238			0.257		0.275	
				Range				.034	.026		.021			.006		.010	
C[3]	397-13	3	Air	2 Average					.325			d .390			d 0.415		
				Range					.001								
D[4]	875-12	2	Air	1	.118	.191	1.97	.229	.294				.340				
D[3]	863-12	2	Air	2 Average	.200	.173	.190	.209	.254				.297				
				Range	.029	.012	.015	.020	.025				.037				
D[5]	882-12	2	Air	2 Average	.188	.186	.197	.220	.263				.309				
				Range	.026	.017	.017	.017	.014				.011				
D[1]	378-13	2	Air	2 Average				.149	.153		.003			+.353			+.408
				Range				.032	.031		.205			.623			.745
E[1]	312-13	2	Air	2 Average				.139	.152		.160		.158				.168
				Range				.009	.011		.027		.050				.054
F[1]	459-13	2	Air	1				.065	.112				.096				
G[1]	1079-12	2	Air	6 Average	.087	.094	.102	.108	.142				.180				
				Range	.026	.025	.058	.046	.053				.046				

G[1]	1079–12	3	Air	2 Average	.115	.141	.178	.180				d .262					
				Range	.010	.018	.008	.004									
G[7]	442–13	2	Air	2 Average				.169		.198			.229				.252
				Range				.025		.006			.002				.008
H[2]	901–12	3	Air	2 Average	.058	.070	.082	.084	.128				.156				
				Range	.002	.004	.001	.001	.001				.002				
I[1]	1208–12	3	Air	1, average				.155	.199			.289					
K[1]	788–12	2	Air	2 Average	.152	.203	.221	.222	.277				.327				
				Range	.019	.016	.018	.021	.010				.005				
L[1]	774–12	3	Air	2 Average	.136	.171	.190	.200	.239				.336				
				Range	.016	.047	.058	.064	.069				.138				
M[1]	669–12	3	Air	2 Average	.119	.162	.174	.181	d .234				d .301				
				Range	.012	.011	.006	.006									
A[1]	345–13	2	Water	2 Average				+.103			+.132			+.179			+.210
				Range				.045			.034			.035			.030
B[3]	303–12	2	Water	1	+.055	+.077											
C[2]	243–13	3	Water	2 Average				+.111	+.109		+.100			+.136		+.164	
				Range				.040	.115		.038			.037		.030	
C[3]	397–13	3	Water	2 Average					+.073			+.199			+.152		
				Range					.005			.009			.018		
D[1]	378–13	2	Water	2 Average				+.104	+.117		+.106			+.137			+.163
				Range				.010	.005		.012			.016			.013
E[1]	312–13	2	Water	2 Average				+.118	+.120		+.114			+.147			+.176
				Range				.006	.010		.007			.013			.002
F[1]	459–13	2	Water	2 Average				+.077	+.123				+.196		+.243		
				Range				.021	.022				.005		.000		
F[3]		3	Water	1	+.090	+.090	+.110										
G[7]	442–13	2	Water	2 Average				+.056		+.061			+.094			+.126	
				Range				.004		.012			.004			.017	

[a] All American Portland cements except L, which is a white Portland, and M, which is a nonstaining cement.
[b] See p. 11.
[c] All changes are contractions except where marked with a plus (+) sign.
[d] Only one result obtained.
[e] Only two results in average.

TABLE 10

Summary of Linear Expansion Tests of Neat Cement Prisms Treated in High-Pressure Steam

Brand of cement	Lab. No.	Type of cement[a]	Test piece	Age when treated (days)	Steam pressure (lbs. per sq. in.)	Periods in steam	Total time in steam (hours)	Linear expansion in per cent of original length
A[1]	345–13	2	1	1	300	1	3	1.88
			2	1	300	1	3	1.85
								Av. 1.86
A[2]	406–13	3	1	1	300	1	3	.13
			2	1	300	1	3	.13
								Av. .13
B[3]	303–12	2	1	5	180	1	5	4.20
			[b] 2	1	180	1	5	4.40
			[b] 2	2	180	2	5	4.80
			3	21	275	1	5	4.20
B[1]	948–12	2	1	1	300	1	3	2.70
C[2]	243–13	3	1	1	300	1	3	.38
			2	1	300	1	3	.39
C[1]	397–13	3	1	1	300	1	3	.09
C[4]	1209–12	3	1	4	300	1	3	.14
D[1]	378–13	2	1	1	300	1	3	5.45
			2	1	300	1	3	4.20
								Av. 4.82
D[3]	....	3	[c] 1	2	100	1	5	.20
			[c] 1	3	100	2	5	.29
			[c] 1	4	100	4	5	.29
			[c] 1	9	180	6	5	.30
			[d] 2	1	100	1	5	.18
			[d] 2	3	100	2	5	.28
			[d] 2	11	100	7	5	.31
E[1]	312–13	1 or 2	1	1	300	1	3	6.50
			2	1	300	1	3	10.80
								Av. 8.65
E[2]	421–13	3	1	1	300	1	3	.12
			2	1	300	1	3	.12
								Av. .12

[a] See p. 11.
[b] Same test piece was treated second time.
[c] This was same test piece subjected to steam at various pressures for 5 hours each time.
[d] Same test pieces tested at 100 pounds steam for periods of 5 hours each.

TABLE 10—Continued

Brand of cement	Lab. No.	Type of cement [a]	Test piece	Age when trea.ed (days)	Steam pressure (lbs. per sq. in.)	Periods in steam	Total time in steam (hours)	Linear expansion in per cent of original length
F[1]	459–13	2	1	1	300	1	3	(e)
			2	1	300	1	3	(e)
F[2]	178–192–12	3	f 1	1	100	1	5	.09
			f 1	2	100	2	5	.10
			f 1	3	180	3	5	.13
			f 1	6	180	5	5	.13
			g 2	1	180	1	5	.13
			g 2	2	180	2	5	.14
			g 2	3	180	3	5	.21
			g 2	4	180	4	5	.31
F[3]	195–214–12	3	h 1	1	100	1	5	.06
			h I	2	180	2	5	.07
			h 1	5	180	4	5	.07
			h 2	1	180	1	5	.09
			h 2	3	180	3	5	.11
F[4]	251–60–12	3	i 1	1	100	1	5	.16
			i 1	2	100	2	5	.15
			i 1	4	180	4	5	.16
			i 1	7	180	6	5	.16
G[2]	1080–12	2	1	3	300	1	3	4.30
G[7]	442–13	2	1	1	300	1	3	5.92
			2	1	300	1	3	6.08
G[2]	1081–12	3	1	1	300	1	3	.13
G[1]	1079–12	3	1	1	300	1	3	.12
G[8]	435–12	3	j 1	2	180	1	5	.10
			j 1	3	180	2	5	.11
			j 1	7	180	6	5	.14
H[1]	532–12	3	k 1	1	180	1	5	.05
			k 1	2	180	2	5	.14
I[1]	1208–12	3	1	4	300	1	3	.13

[e] Completely disintegrated.
[f] Same test piece tested at various pressures for a period of 5 hours each time.
[g] Same test piece tested several times for periods of 5 hours each time.
[h] Same test piece treated several times for a period of 5 hours each time.
[i] Same test piece treated several times at various pressures for periods of 5 hours each.
[j] This test was made after this cement became type 3. Same test piece treated several times for periods of 5 hours each time.
[k] Same test piece.

TABLE 10—Continued

Linear Expansion of Standard Specification Cement and Mortar Treated in High-Pressure Steam

Brand of cement	Lab. No.	Type of cement	Composition of test piece	Age when treated (days)	Steam pressure (pounds)	Testing periods	Total time in steam (hours)	Linear expansion in per cent of original length
B3	303 to 314–12	2	Neat	1	180	1	5	4.7
			1:1 standard sand	1	180	1	5	4.6
			1:2 standard sand	1	180	1	5	3.3

4. RELATION BETWEEN FINENESS OF CEMENT AND SOUNDNESS IN HIGH-PRESSURE STEAM

A cement passing the standard fineness and soundness tests but showing unsoundness in the qualitative high-pressure steam test was separated into that passing the No. 200 sieve and that retained on the No. 200 sieve. A pat was made of the cement passing the No. 200 sieve and treated in steam at 300 pounds pressure for one hour, total time in high-pressure boiler being three hours, and when examined it was found perfectly sound. A mixture of one part cement passing the No. 200 sieve and one part of the material retained on that sieve was then made, from which a pat was molded and subjected to the qualitative high-pressure steam test, with the result that the pat completely disintegrated under treatment. A pat containing a mixture of two parts of the cement passing the No. 200 sieve and one part of the retained material was similarly tested and likewise disintegrated in high-pressure steam, but the disintegration was not as complete as in the 1:1 mixture. Further, the coarse material retained on the No. 200 sieve from a cement that was sound in the qualitative high-pressure steam test was made into a pat and exposed to high-pressure steam, with the result that the pat completely disintegrated. This same cement when tested as received by the quantitative high-pressure steam test showed a 25 per cent increase in tensile strength for the treated cement over the untreated. Many of the routine cement samples that passed the high-pressure steam test were relatively coarse cements, i. e., only

75 to 80 per cent passing the No. 200 sieve. One cement having 79 per cent passing the No. 100 sieve and 61 per cent passing the No. 200 sieve was sound in the high-pressure steam test.

5. EFFECT OF AGE ON THE SOUNDNESS OF CEMENTS THAT ORIGINALLY ARE UNSOUND IN HIGH-PRESSURE STEAM TESTS

About 30 samples of cement, all sound in the standard atmospheric steam test but unsound in the qualitative high-pressure steam test, were stored in air-tight glass jars and retested in high-pressure steam at various intervals. The results of these tests indicate that a cement originally unsound in high-pressure steam will become sound, according to this test, in from two to six months. On some of the cements a number of pats were made at a time when the cement was unsound in high-pressure steam. These pats, which were stored in both air and water, were tested at subsequent intervals, and it was found that most of them passed the high-pressure steam test after storing for from six months to one year. A sample of one cement which was unsound in the standard atmospheric steam test stored in a cotton bag in the laboratory became sound in three weeks; stored in a Mason jar with cover tightly screwed on, it became sound in four months; and sealed in a glass jar from which the air was exhausted, it was still unsound at the end of two years.

V. SUMMARY

The general soundness tests show that some cements mixed neat, which are sound according to the standard specification atmospheric steam test and unsound after exposure in high-pressure steam, exhibit signs of unsoundness when stored under normal conditions in dry air. This unsoundness may require nine months or more to develop where the test pieces are of neat cement.

The tensile strength tests of 1:3 mortar fail to show that a cement passing the high-pressure steam test is superior in cementing value to a cement which does not pass this test but passes the standard specification test. The briquettes made from the cement unsound in atmospheric steam do not show inferiority in strength to those

made of sound cement. A striking feature of these tests at the later periods is the high value attained by two of the cements which were unsound in the atmospheric steam test.

The compressive strength tests of 1:3 mortar in 2-inch cubes show a comparatively low strength at the earlier periods for type 1 cement, which is unsound in the atmospheric steam test, and a high strength at all periods of type 3 cements which pass the high-pressure steam test. In all cases where several samples of the same brand, some classified as type 2 and some as type 3 cement, the test pieces which contain the type 3 cement give higher strength values throughout.

The compressive strength tests of the concretes composed of one part Portland cement to two parts sand and four parts of gravel show a superiority at the earlier periods of type 2 and type 3 cements, which are sound in atmospheric steam and high-pressure steam, respectively, over the type 1, which is unsound in atmospheric steam, and little or no difference in strength between type 2 and type 3 cements at any periods.

There is no consistent relation existing between the strength of type 2 and type 3 of the same brand, sometimes type 2 being stronger and at other times type 3 is stronger. There is a large range in the strength of samples of the same brand received at different times irrespective of the type, and a considerable range in the different brands both for type 2 and type 3. It was noted that cylinders tested in the winter and spring months consistently gave lower values than similar cylinders tested in the summer and fall, but no explanation can be offered for this variation. It is interesting to note that one of the cements giving one of the strongest concretes throughout was taken from a delivery rejected on account of unsoundness in steam and is a type 1 cement.

The results of the tests of linear change of neat cement prisms of both type 2 and type 3 cements as a whole show no difference that could be attributed to the type of cement when the prisms are stored in air and water. There is more variation between the different brands than between different types of the same brand. However, in one case a neat cement containing type 2 cement (marked D^1) at four months began to expand in air and continued

to expand to a great degree up to the last period measured. This test prism also began to warp and show signs of disintegration. Several of the other prisms containing type 2 cement showed some warping, but no prisms containing type 3 cement exhibited any warping or other signs of unsoundness. (See Fig. 6.)

The treatment of neat cement prisms in high-pressure steam showed an expansion of from 1.86 to 10.80 per cent for type 2 cement (in some cases the prisms completely disintegrated), while prisms containing type 3 cement expanded in high-pressure steam from less than 0.1 up to 0.31 per cent. Increasing the pressure from 100 to 300 pounds affects the amount of expansion of the prisms but little, if any. The addition of a small amount of water-repellant compound to the cement does not affect the amount of its change of length when stored in air or water. The addition of sand to a prism containing type 2 cement reduces the amount of expansion in high-pressure steam for a 1:1 mortar to 96 per cent of that of the neat, and for a 1:2 mortar to 69 per cent of the neat, all being subjected to the same high-pressure steam treatment.

Seventy per cent of a total number of 51 brands of cement tested passed the high-pressure steam test.

Of cements normally unsound in the standard atmospheric steam or high-pressure steam test, if the finer sized particles are removed and tested separately, they will generally be found more sound than the original cement tested in the same manner, and in many cases they will be found entirely sound. Further, if the coarse particles of a cement which is sound after exposure in high-pressure steam are removed and tested separately, they may be found to be unsound in this test. While fineness is not essential to soundness, it appears to be the coarse particles of a normally unsound cement which cause the expansive action and the cracking and disintegration of the pat.

A cement originally unsound in the high-pressure steam test will usually be found sound if exposed to this test after aging from two to six months.

If a cement which will not meet the requirements of the high-pressure steam test is mixed with water and formed into a pat,

it sometimes becomes sufficiently sound to pass the high-pressure steam test, if the pat is stored from six months to a year in either air or water prior to exposing to high-pressure steam.

The maximum tensile strength of sound cement exposed to steam appeared to be attained at a pressure not exceeding 150 pounds per square inch; but this may vary with different brands and different durations of the steam treatment. Type 2 cement begins to fail when subjected to steam at a pressure as low as 25 pounds.

VI. CONCLUSION

1. The high-pressure steam test should be made on all cements that are incorporated in cement, mortar, or concrete products that are to be cured in steam at pressures above atmospheric.

2. The high-pressure steam test may be of value as forecasting the behavior of neat cement or a very rich mortar when exposed under normal conditions in dry air, but it will not forecast the behavior of cements in concretes as normally exposed.

3. The cement passing the high-pressure steam test is not superior in cementing quality, as determined from the compressive strength of concretes, to cement that fails to pass this test.

4. The cement passing the high-pressure steam test does not make more permanent or durable concrete than cement which meets the requirements of the standard specification but fails to pass this test.

5. Cement failing to pass the standard specification atmospheric steam test but meeting the other requirements of the standard specification shows in some instances a normal strength in concrete.

6. For practical work under normal conditions of construction, the results of this investigation fail to show that the high-pressure steam test is of value as a means of determining the ultimate soundness of concrete.

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